Optional Soil Moisture Sensor Protocol

Welcome Introduction Protocols Learning Activities Appendix

Purpose

To measure the water content of the soil based on the electrical resistance of soil moisture sensors.

Overview

Students install soil moisture sensors in holes that are 10 cm, 30 cm, 60 cm, and 90 cm deep. They take daily readings of soil moisture data by connecting a meter to the sensors and using a calibration curve to determine the soil water content at each depth.

Student Outcomes

Students will be able to measure soil moisture from a sensor and record and report soil moisture data. Students will be able to relate soil moisture measurements to precipitation, air temperature and the physical and chemical characteristics of the soil. Students will understand the role of soil moisture in the hydrologic cycle and in phenology.

Science Concepts

Earth and Space Sciences

Earth materials are solid rocks, soil, water, biota, and the gases of the atmosphere.

Soils have properties of color, texture, structure, consistence density, pH, fertility; they support the growth of many types of plants.

The surface of Earth changes.

Soils consist of minerals (less than 2 mm), organic material, air and water.

Water circulates through soil changing the properties of both the soil and the water.

Physical Sciences

Objects have observable properties.

Scientific Inquiry Abilities

Identify answerable questions.

Design and conduct an investigation.

Use appropriate tools and techniques including mathematics to gather, analyze, and interpret data.

Develop descriptions and explanations, predictions and models using evidence.

Communicate procedures and explanations.

Time

10 minutes per day

Level

Middle and Secondary

Frequency

Daily

Reinstallation and calibration every two years

Materials and Tools

Soil Auger

Meter stick

Four soil moisture sensors

Four 10 cm long x 7.6 cm diameter PVC tube or tin cans for wire holders at the surface

Two 4-L soil holding/mixing buckets

Water for making mud balls (0.5 L)

One 1 m x 2 cm PVC guide tube

Soil packing stick (e.g. an old broom handle)

Pen or pencil

Soil moisture meter

Graph paper

Calculator

Daily Soil Moisture Sensor Data Sheet

Semi-Annual Soil Moisture Sensor Calibration Data Sheet

Materials for the *Gravimetric Soil Moisture Protocol*

Preparation

Locate a soil moisture study site and fill out a *Soil Moisture Site Definition Sheet*. Collect the tools and materials. Prepare the PVC guide tube. Soak the sensor blocks overnight.

Prerequisites

Gravimetric Soil Moisture Protocol

Optional Soil Moisture Sensor Protocol - Introduction

The *Gravimetric Soil Moisture Protocol* measures soil moisture as the amount of water per unit mass of soil (see the *Gravimetric Soil Moisture Protocol* for more information). The technique used in this protocol measures soil moisture through a sensor that is sensitive to the amount of water per unit volume as well as how tightly the water is bound to the soil. The sensor measures the electrical conductivity of moisture that enters a ceramic block from the surrounding soil. The sensor reading is a function of the ceramic porosity, the soil texture and the amount of total dissolved solids (TDS) in the soil water.

To be scientifically useful, the soil moisture readings must be converted to soil water content values. Because this conversion is sensitive to characteristics of the individual Soil Moisture Site, one or more calibration curves must be developed. Students take measurements at least 15 times following the appropriate parts of the *Gravimetric Soil Moisture Protocol – Depth Profile* to obtain the data to determine these curves.

Teacher Support

Measurement Procedures

Students use an auger to dig holes to depths of 10 cm, 30 cm, 60 cm and 90 cm. They install soil moisture ceramic block sensors in each hole following the *Installation of Soil Moisture Sensors Field Guide*. The soil moisture ceramic block sensors must be in complete contact with the surrounding soil. The soil should be broken up and slightly moist before packing it around the sensor during installation.

Once the soil moisture sensors are installed, students should wait at least one week before beginning to report the data to GLOBE. Students take daily readings of soil moisture from meters they connect to the sensors following the *Reading the Soil Moisture Meter Field Guide*.

Calibration curves must be created to convert soil moisture meter readings to soil water content. To do this, students will conduct gravimetric soil moisture measurements for one or more depths at their Soil Moisture Site. They will need to take measurements at least 15 times over a period of 6 – 8 weeks during which the soil moisture varies from wet to dry. The calibration curves do not have to be developed immediately but should be completed within about six months following installation of the soil moisture sensors. Therefore, time the collection of calibration data for a period when the soil moisture is likely to be changing significantly. Generally, this means start the measurements when the soil is wet and will be drying significantly over the coming two months. Obtaining the calibration data from a full drying cycle is desired.

There is no need to take calibration measurements when soil moisture meter readings are close to one another. The key is to cover as wide a range of moisture conditions as possible. Students can begin taking a calibration sample and then wait for the day when the meter reading has changed significantly before collecting another sample. What constitutes a significant change varies across the range of meter readings. If you are using a Delmhorst meter, you want 5 or more calibration points at meter readings from 85 to

100 while you only need 5 calibration points over the range of 1 to 40. For the Watermark and similar meters, you should obtain at least 5 calibration points at meter readings between 1 and 15 while 5 calibration points between meter readings of 100 and 199 should be enough. Regardless of the meter, the end-points of the meter (0 and 100 for Delmhorst and 0 and 200 for Watermark) should not be used in determining your calibration curves. Gravimetric soil moisture data collected for calibration should be reported to GLOBE.

If the soil profile is uniform and the sensors are identical, then calibration for all four sensors can be accomplished comparing sensor and gravimetric soil moisture samples at the 30 cm depth. To determine if the soil is uniform at the different depths, students should perform the *Soil Particle Density* and *Particle Size Distribution Protocols* on soil samples from the four depths – 10 cm, 30 cm, 60 cm, and 90 cm. The soil particle density and texture at 10 cm, 30 cm, 60 cm, and 90 cm are compared. If:

1. the soil particle density at two or more depths do not differ by more than 20%, and
2. the textures at these depths are either the same or fall in adjacent areas on the *Soil Texture Triangle*,

then the same calibration curve may be used for these depths. So, depending on the soil at your site, you only may need to determine one calibration curve (at 30 cm depth) or you may have to determine separate curves for up to four depths.

You may have students determine the soil particle density and texture from samples taken when the soil moisture sensors are installed or take gravimetric soil moisture samples from all four depths the first time calibration samples are taken and use the dried soil samples to perform the *Soil Particle Density* and *Particle Size Distribution Protocols*.

If you do not wish to have students perform the *Soil Particle Density* and *Particle Size Distribution Protocols* to determine the uniformity of your soil, simply develop individual calibration curves for all four depths.

While GLOBE will create calibration curves for you using your calibration data, students can create their own calibration curves following the *Creating a Calibration Curve Lab Guide*.

Students should monitor the sensors daily for soil moisture variations. They report both the raw meter reading and calibrated values. If they have not finished their calibration curves, they should report the raw values and enter the calibrated values at a later time.

Students should not monitor the sensors when the ground is frozen because this limits the electrical conductivity of any pore waters.

Every two years students need to reinstall and recalibrate the soil moisture sensors.

Managing Materials

Students can use any ceramic block sensors that meet GLOBE specifications. Sensors manufactured by Watermark are known to meet GLOBE specifications and work well for this measurement. There are two soil moisture meters suggested for use with these sensors. One is manufactured by Delmhorst and reads 0 to 100 (dry to wet). The other is made by Watermark and reads 0 to 200 (wet to dry). Please contact the GLOBE soil moisture science team if you have a different kind of sensor or meter.

Supporting Activities

Students can examine the characteristics of the soil profile at their Soil Moisture Study Site. Students should follow the *Soil Characterization Site Exposure – Auger Method* procedures for digging the soil moisture sensor holes. They should follow the *Soil Characterization Protocol* when digging the 90 cm hole. Students should remember to place the extracted soil on a plastic sheet, tarp or board in the same order as it is removed from the hole. Students measure the depth of the hole after each auger extraction and adjust the area/length of the laid-out sample to preserve the profile-depth relationships.

Questions for Further Investigation

What is the annual cycle of soil moisture at your location? How consistent is this pattern from year to year? Can you explain the major differences between two consecutive annual cycles?

How much rain does it take before you see a change in your 90 cm reading? How long does it take to see this wetting front at each of the four depths?

What other parts of the world have soil moisture patterns that look like yours?

Try to find soil moisture data from part of the world in drought. How would you assess the magnitude of drought from the soil moisture record?

Frequently Asked Questions

1. The soil particle density and texture differs at the different depths at our site. How many calibration curves must we develop?

All depths with similar soil particle densities (within 20%) and textures (the same or adjacent on the *Soil Texture Triangle*) may share the same calibration curve.

The following table describes seven possible situations and states what calibrations curves should be developed and how they should be used.

Situation	What to do
Each depth is different from all the others	Develop individual calibration curves for each depth.
30 cm, 60 cm, and 90 cm are similar but 10 cm is different	Develop a calibration curve for 10 cm and use it for 10 cm and develop a separate curve for 30 cm and use it for 30 cm, 60 cm, and 90 cm.
10 cm, 30 cm, and 60 cm are similar but 90 cm is different	Develop a calibration curve for 90 cm and use it for 90 cm and develop a separate curve for 30 cm and use it for 10 cm, 30 cm, and 60 cm.
10 cm and 30 cm are similar, 60 cm and 90 cm are similar but different from 10 cm and 30 cm	Develop a calibration curve for 30 cm and use it for 10 cm and 30 cm; develop a separate curve for 60 cm and use it for 60 cm and 90 cm.
30 cm and 60 cm are similar, but 10 cm and 90 cm differ from one another and from 30 cm and 60 cm	Develop separate calibration curves for 10 cm, 30 cm, and 90 cm; use the 30 cm curve for 30 cm and 60 cm.
10 cm and 30 cm are similar, but 60 cm and 90 cm differ from one another and from 10 cm and 30 cm	Develop separate calibration curves for 30 cm, 60 cm, and 90 cm; use the 30 cm curve for 10 cm and 30 cm.
60 cm and 90 cm are similar, but 10 cm and 30 cm differ from one another and from 60 cm and 90 cm	Develop separate calibration curves for 10 cm, 30 cm, and 60 cm; use the 60 cm curve for 60 cm and 90 cm.

Installation of Soil Moisture Sensors

Field Guide

Task

To install the soil moisture sensors

What You Need

- ❑ Soil Auger
- ❑ Meter stick
- ❑ Four soil moisture sensors
- ❑ Four 10 cm long x 7.6 cm diameter PVC tube or tin cans for surface wire holders
- ❑ Two 4-L soil holding/mixing buckets
- ❑ Water for moistening the soil (0.5 L)
- ❑ One 1 m x 2 cm PVC guide tube
- ❑ Soil packing stick (e.g. an old broom handle)
- ❑ Pen or pencil

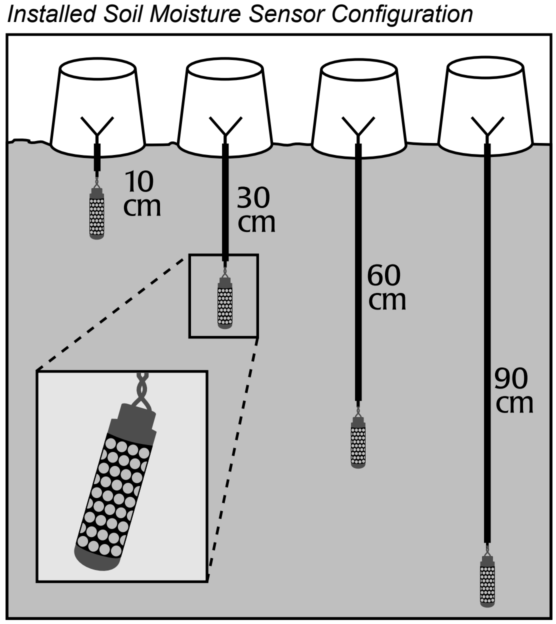
In the Field

1. Place the sensors into a container of water and **soak overnight.**
2. Auger 4 holes next to one another to the appropriate depth for each soil moisture sensor (10 cm, 30 cm, 60 cm or 90 cm). Each sensor will go in its own hole.
3. Place two large handfuls of soil extracted from the bottom of each hole into a small bucket or similar container. Remove any rocks. Add a small amount of water and stir to create soil that is moist enough that it stays together when pressed into a ball.
4. Drop the moist soil ball to the bottom of the hole. Make sure it reaches the bottom.
5. Push the wire lead from one of the sensors through the PVC guide tube.
6. Pull the end of the wire lead until the sensor fits firmly against the other end of the guide tube. Lower the tube into the hole with the sensor going in first. While holding the wire lead at the top of the pipe, gently push the tube down until the sensor is set into the moist soil at the bottom of the hole.
7. Hold the sensor in place with the guide tube while you begin to backfill the hole. As you slowly add soil to the hole, gently pack or tamp it with a broom handle or similar pole. After the sensor is covered, remove the guide tube. Continue adding soil a few handfuls at a time and tamping firmly as you backfill the hole. Hold on to the wire lead as you backfill so that it will come straight to the surface.
8. Place a short piece (about 10 to 20 cm long) of PVC pipe, tin can, or coffee can (with the top and bottom removed) around the wire lead at the surface to protect it and make it visible to anyone walking in the vicinity. Label the pipe or can with the appropriate sensor depth.

9. Put the wire through the pipe or can and press the pipe or can 2 to 5 cm into the soil to keep it in place. Do not cut the wire, but wind up the free end extending out of the ground and place it in the pipe or can to keep it out of the way between measurements. A small empty can (e.g. a soup can) should be inverted over the end of the PVC pipe to keep the rain out.
10. Repeat the above steps for each sensor.

Note: Do not report measurements for a week after installation. The sensors require at least one week to equilibrate to natural conditions. The wire leads are fragile, especially where they connect to the meter. If the end of the wire leads to the soil moisture sensors break, peel back the wire insulation and make new leads. It is important to leave enough wire above the ground for this.

Installed Soil Moisture Sensor Configuration



Determining Soil Uniformity With Depth

Field and Lab Guide

Task

Determine whether the soil particle density and texture are uniform at 10 cm, 30 cm, 60 cm, and 90 cm depths

What You Need

- ❑ Soil auger
- ❑ Meter stick
- ❑ Four soil containers (bags or soil moisture sample cans)
- ❑ Materials for the *Soil Particle Density Protocol*
- ❑ Materials for the *Particle Size Distribution Protocol*
- ❑ Soil drying oven

A calibration curve for your soil moisture sensor at 30 cm depth must be developed for conversion from meter readings to soil water content. There is no need to develop calibration curves for other depths unless they differ significantly in soil particle density or texture. The following steps are how you determine this.

In the Field

1. Near the holes where your soil moisture sensors are installed, use the auger to take samples from 10 cm, 30 cm, 60 cm, and 90 cm depths and store them for lab analysis. Samples should be at least 200 g each. Labels should give the date and depth.

   Note: If you are using these samples for the *Gravimetric Soil Moisture Protocol*, follow the steps of that protocol for taking, storing, weighing, and drying the samples, and then, use the dry samples in the steps given below beginning with step 4.

2. Replace the remaining soil in the hole with soil from the deepest depth going in first and soil from near surface going in last.

In the Lab

3. Dry your soil samples.
4. Determine the soil particle density of each sample following the *Soil Particle Density Protocol*.
5. Determine the texture of each sample following the *Particle Size Distribution Protocol*.
6. Compare the particle densities at 10 cm, 60 cm, and 90 cm, with the value at 30 cm. If the value for a depth differs by more than 20% from the density at 30 cm, you should produce a separate calibration curve for that depth.
7. Locate the textures at the four depths on the *Soil Texture Triangle*. If the texture at 10 cm, 60 cm or 90 cm depth is not in the same area on the Triangle as the texture at 30 cm depth or if it is not in an area bordering the texture at 30 cm depth on the *Triangle*, produce a separate calibration curve for that depth.
8. You may wish to return your samples to the appropriate depths when you take samples for building your calibration curve.

Reading the Soil Moisture Meter
Field Guide

Task
To take daily measurements from the soil moisture sensors

What You Need
- ❑ Properly installed soil moisture sensors
- ❑ Soil moisture meter
- ❑ Pen or pencil
- ❑ *Daily Soil Moisture Sensor Data Sheet*

Note: Test the soil moisture meter to ensure it is functioning properly according to the manufacturer's instructions. Do this before each use. Each meter has its own operating procedures. The instructions below are for the Delmhorst and Watermark meters.

In the Field
1. Complete the top of your *Daily Soil Moisture Sensor Data Sheet.*
2. Locate the sensor in the 10 cm deep hole.
3. Uncover the sensor's wire leads.
4. Connect the soil moisture meter to the wire leads of the sensor.
5. Push the READ button. Wait for the meter to reach a constant value.
6. Record the date, time, saturation conditions, and soil moisture meter reading on the *Daily Soil Moisture Sensor Data Sheet* in the appropriate depth column. If the Delmhorst meter reads a negative value (and the soil is dry), record a zero.
7. Disconnect the meter and store the wire leads.
8. Replace the cover over the PVC pipe and wire leads.
9. Repeat steps 3-8 for each of the remaining sensors (30 cm, 60 cm, and 90 cm).
10. Convert each meter reading to soil water content using your calibration curve.

Calibration of Soil Moisture Sensors
Field Guide

Task
To calibrate the soil moisture sensors.

What You Need
- ❑ Soil Auger
- ❑ Meter stick
- ❑ Pen or pencil
- ❑ Properly installed soil moisture sensors
- ❑ Soil moisture meter
- ❑ Materials for the *Gravimetric Soil Moisture Protocol* (i.e., cans, oven, trowel, marking pen)
- ❑ *Biannual Soil Moisture Sensor Calibration Data Sheet(s)*

In the Field
1. Complete the top portion of your *Biannual Soil Moisture Sensor Calibration Data Sheet.*
2. Take readings from the soil moisture sensors following the process outlined in the *Reading the Soil Moisture Meter Field Guide*. Record this reading in column G, Corresponding Soil Moisture Meter Reading, of the *Biannual Soil Moisture Sensor Calibration Data Sheet(s)*.
3. Select a random location within 5 m of the sensor holes.
4. Clear away any surface debris.
5. Use the auger to collect samples for the *Gravimetric Soil Moisture Protocol* from each depth for which you are developing a calibration curve. Place each soil sample in a container and number the container.
6. Backfill the hole (last out, first in) and replace the surface cover.
7. Record the date, time, depth(s) and container number(s) in your science notebooks.
8. Determine the soil water content of each sample following the *Gravimetric Soil Moisture Protocol Lab Guide*.
9. Record the date and time of your measurement, the wet, dry, and container masses on the *Biannual Soil Moisture Sensor Calibration Data Sheet*. Calculate the water mass, dry soil mass and soil water content and record their values on the *Data Sheet*.
10. Report your gravimetric soil moisture data to GLOBE.
11. Repeat steps 2 – 10 about fourteen times as the soil moves through one or two complete drying cycles. Wait until your meter reading changes significantly before collecting another gravimetric sample.
12. Report your calibration data to GLOBE and a calibration curve will be created, used to convert your meter readings to soil water content and sent to your school.

Creating a Calibration Curve - Watermark Meter

Lab Guide

Task

To create a calibration curve

What You Need

- ❑ Pen or pencil
- ❑ Graph paper or appropriate spreadsheet graphing software
- ❑ *Biannual Soil Moisture Sensor Calibration Data Sheet* with 15 or more pairs of readings for each depth for which you are developing a calibration curve
- ❑ Calculator or computer

In the Lab

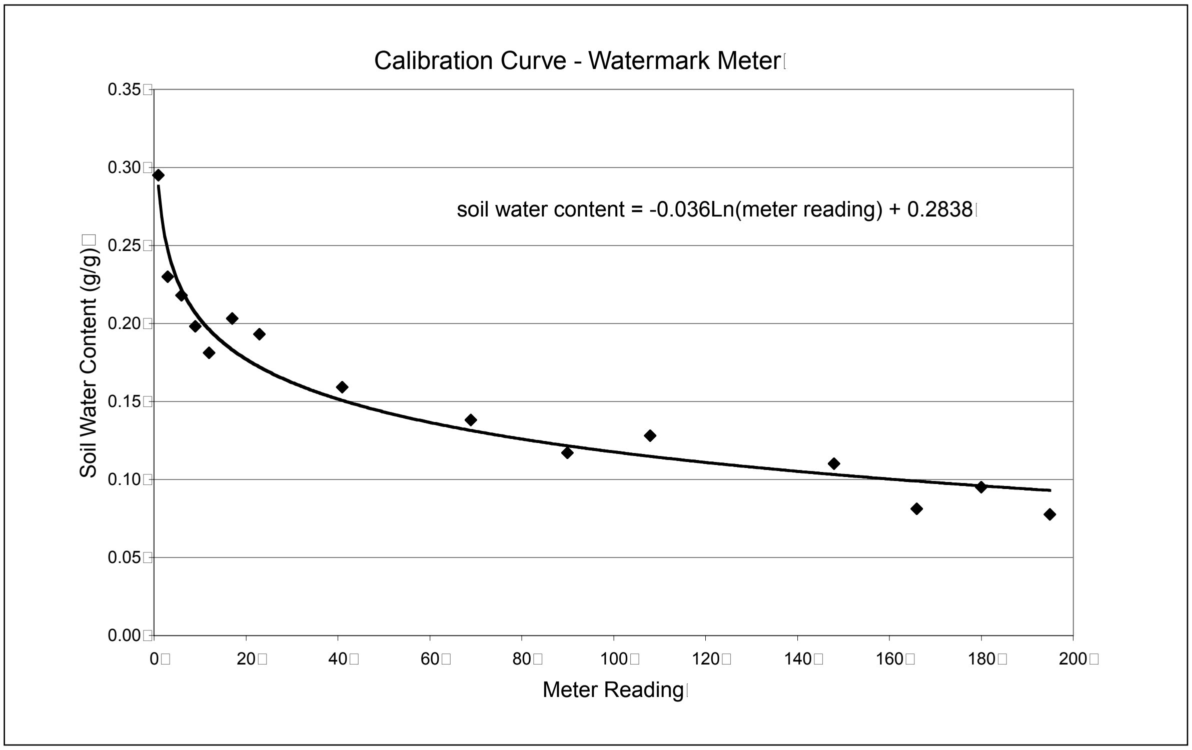
1. Plot all the pairs of readings for a single depth with soil water content on the Y-axis and the corresponding soil moisture meter readings on the X-axis. This can be done using spreadsheet software.
2. Draw or calculate the *best-fit natural logarithmic curve* through your data points.

   $$\text{Soil Water Content} = a \ln(\text{Soil Moisture Reading}) + b$$

   Your data should span a broad range of soil moistures. This will be your calibration curve, which you will use to convert your meter readings to soil water content values.

   Note: If you have any questions about creating your calibration curve or if you need any assistance with the curve, contact the GLOBE Help Desk or your country coordinator and ask for help from the appropriate GLOBE scientist.
3. Mail or email a copy of your curve and of your corresponding *Biannual Soil Moisture Sensor Calibration Data Sheet* to GLOBE following the directions for submitting maps and photos given in the *How to Submit Photos and Maps* section of the *Appendix* of the *Implementation Guide*. If while taking soil moisture measurements you get meter readings either higher or lower than any of the readings on your data sheet, take a gravimetric sample, and use the values you measure for this sample to extend your calibration curve. Send a copy of your revised calibration curve and extended *Biannual Soil Moisture Sensor Calibration Data Sheet* to GLOBE.

Example of a Soil Moisture Sensor Calibration Curve for a Watermark Meter



Creating a Calibration Curve - Delmhorst Meter

Lab Guide

Task

To create a calibration curve

What You Need

- ❑ Pen or pencil
- ❑ Graph paper or appropriate spreadsheet graphing software
- ❑ *Biannual Soil Moisture Sensor Calibration Data Sheet* with 15 or more pairs of readings for each depth for which you are developing a calibration curve
- ❑ Calculator or computer

In the Lab

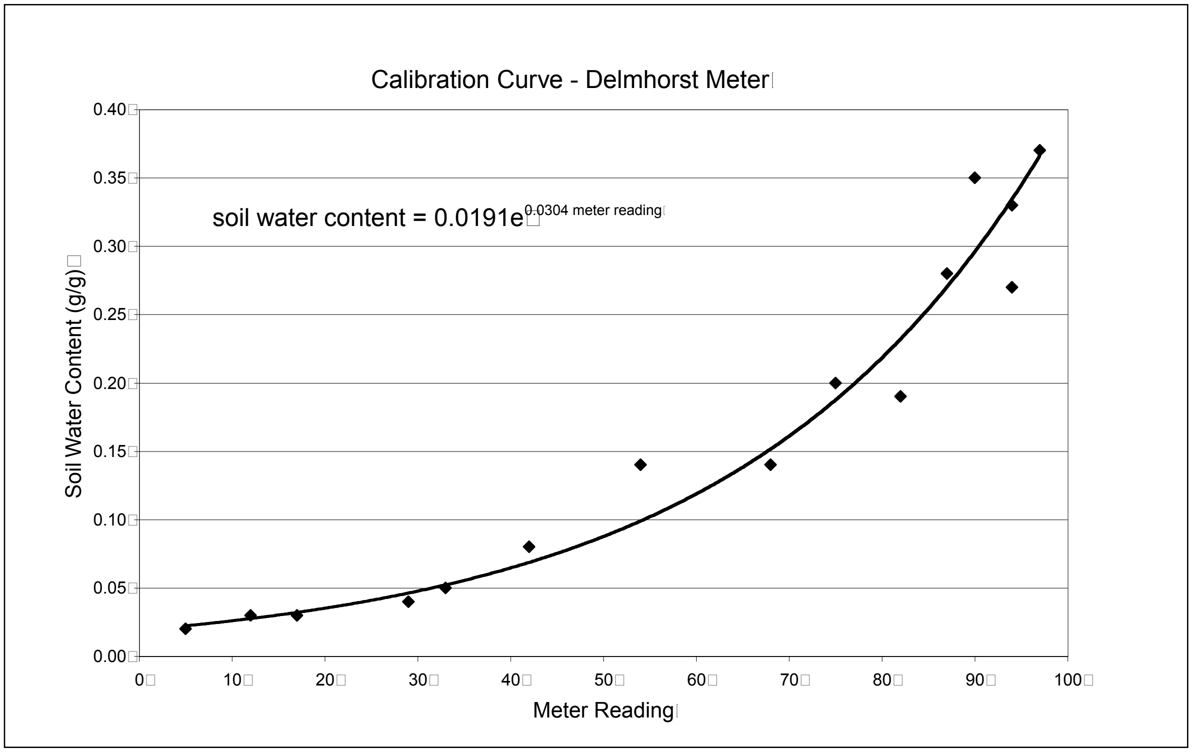
1. Plot all the pairs of readings for a single depth with soil water content on the Y-axis and the corresponding soil moisture meter readings on the X-axis. This can be done using a spreadsheet software.
2. Draw or calculate the *best-fit second order polynomial curve* through your data points.

   $$\text{Soil Water Content} = a \bullet e^{b \bullet \text{meter reading}}$$

   Your data should span a broad range of soil moistures. This will be your calibration curve, which you will use to convert your meter readings to soil water content values.

   Note: If you have any questions about creating your calibration curve or if you need any assistance with the curve, contact the GLOBE Help Desk or your country coordinator and ask for help from the appropriate GLOBE scientist.
3. Mail or email a copy of your curve and of your corresponding *Biannual Soil Moisture Sensor Calibration Data Sheet* to GLOBE following the directions for submitting maps and photos given in the *How to Submit Photos and Maps* section of the *Appendix* of the *Implementation Guide*. If while taking soil moisture measurements you get meter readings either higher or lower than any of the readings on your data sheet, take a gravimetric sample, and use the values you measure for this sample to extend your calibration curve. Send a copy of your revised calibration curve and extended *Biannual Soil Moisture Sensor Calibration Data Sheet* to GLOBE.

Example of a Soil Moisture Sensor Calibration Curve for a Delmhorst Meter



Soil Investigation

Daily Soil Moisture Sensor Data Sheet

School Name: ______________________________

Study Site: ______________________________

Date you started to use this SWC calibration curve: __________

Observations:

Measurement						Soil Moisture Meter Readings				SWC from Calibration Curve			
#	Date	Local Time	Universal (UT)	Is the soil saturated? Yes or No	Observers' Names	10 cm	30 cm	60 cm	90 cm	10 cm	30 cm	60 cm	90 cm
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													

Soil Investigation

Biannual Soil Moisture Sensor Calibration Data Sheet

School Name: ______________________________

Study Site: ______________________________

Drying Method (check one): 95-105 °C oven ___; 75-95 °C oven ___; microwave____

Average Drying Time: __________ (hours or minutes)

Depth (Check one): ❑ 10 cm ❑ 30 cm ❑ 60 cm ❑ 90 cm

Observations:

Measurement												
#	Date	Local Time Hour:min	Time (UT)	Observers' Names	A. Wet Mass (g)	B. Dry Mass (g)	C. Water Mass (A-B)	D. Can Mass (g)	E. Dry Soil Mass (B-D)	F. Soil Water Content (C/E) Reading	G. Soil Moisture Meter Reading
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

Soil Investigation

Biannual Soil Moisture Sensor Calibration Data Sheet – Continued

School Name: ____________________

Study Site: ____________________

Depth (Check one): ❑ 10 cm ❑ 30 cm ❑ 60 cm ❑ 90 cm

Observations:

Measurement											
#	Date	Local Time Hour:min	Time (UT)	Observers' Names	A. Wet Mass (g)	B. Dry Mass (g)	C. Water Mass (A-B)	D. Can Mass (g)	E. Dry Soil Mass (B-D)	F. Soil Water Content (C/E) Reading	G. Soil Moisture Meter Reading
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											